

# Testing the Definition of the ESC Envelope

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## **Introduction**

- The previous effort, including a successful Change Control Request, addressed shrinking the size of the Earth Science Constellations' (ESC) Envelope by reducing the Margin
- Fundamental to the purpose of the Envelope is the case where the argument of perigee of the secondary object circulates from 90 degrees to 270 degrees
- This (“outside of the envelope , always outside the envelope”) case was tested both numerically in a spreadsheet and analytically
- Results showed how it is important to include the fact that a secondary with a different semi-major axis has a different frozen eccentricity value

## Current Definition

Satellite A with Mean semi-major axis  $sma_A$  and a maximum Mean eccentricity  $e_{AMAX}$  is said to be completely *within* the Envelope if and only if:

$$|sma_R - sma_A| + |sma_R * e_R - sma_A * e_{AMAX}| < \text{Margin} + \text{Frozen Orbit Tolerance}$$

Satellite B with Mean semi-major axis  $sma_B$  and a maximum Mean eccentricity  $e_{BMAX}$  is said to be completely *outside* the Envelope (that is, *completely below* or *completely above*) if and only if:

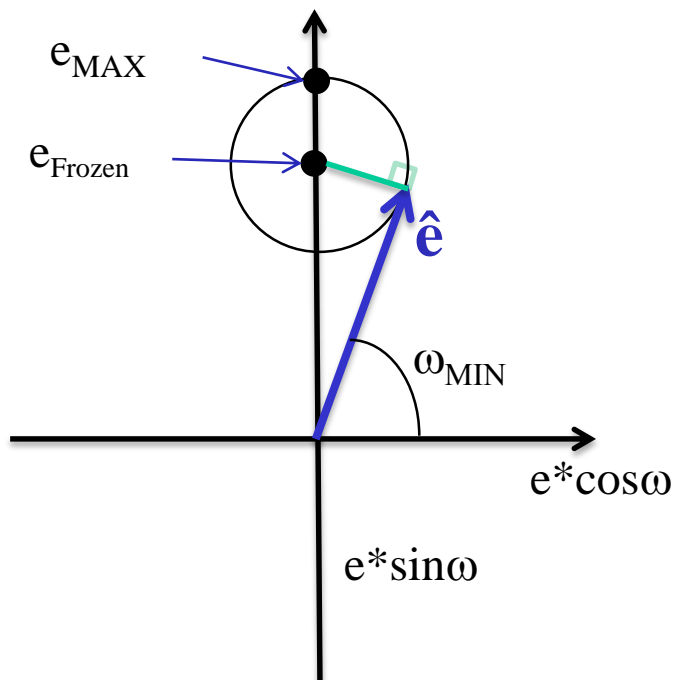
$$|sma_R - sma_B| - |sma_R * e_R - sma_B * e_{BMAX}| > \text{Margin} + \text{Frozen Orbit Tolerance}$$

Where:

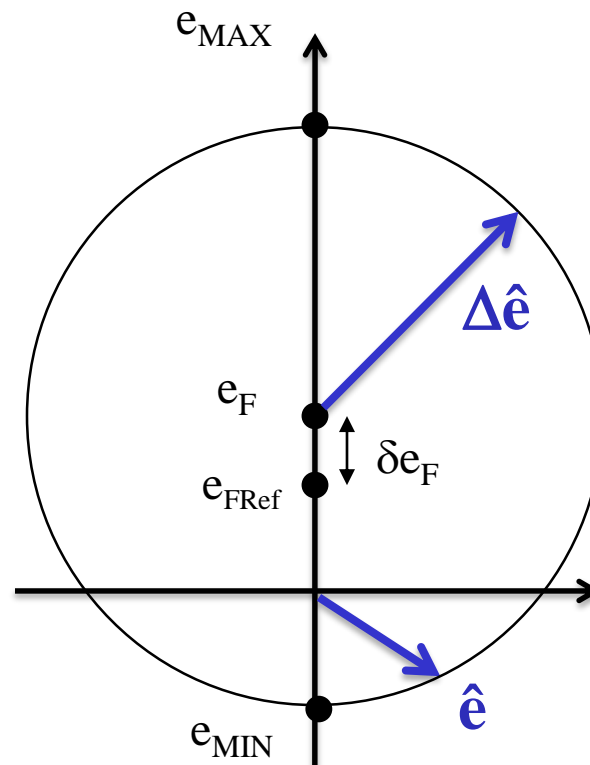
- $sma_R$  = Mean semi-major axis of the 705-km Reference Orbit
- $e_R$  = Mean eccentricity of the 705-km Reference Orbit
- $Margin = 0.5$  km
- *Frozen Orbit Tolerance* based on a maximum eccentricity deviation of 0.0002 (this is equivalent to approximately 1.5 km)

Any satellite that satisfies neither of the conditions of Satellites A or B is said to be *traversing* the Envelope.

# Motion in Eccentricity Space



General Motion  
around Frozen  
Eccentricity



Motion around Frozen  
Eccentricity of Orbit with  
sma less than Reference sma

## Testing the Extreme Cases

- From *Sweetser & Vincent 2013\**: when considering only  $J_2$  and  $J_3$  of the gravity field  $a \cdot e_F$  is a constant for a constant inclination, hence, for small  $\Delta e_F$  and  $\Delta a$  :

$$\Delta e_F / e_F = - \Delta a / a \approx - \Delta a / (a + \Delta a)$$

- First look at apogee to apogee separation when secondary orbit has  $\omega = 90^\circ$

$$\Delta r = a_R(1+e_R) - (a_R+\Delta a) \cdot [1+\Delta e + e_R(1- \Delta a/(a_R + \Delta a))]$$

which simplifies to  $\Delta r = \Delta a - (a_R + \Delta a) \Delta e$

- Next look at separation between reference perigee to secondary apogee when secondary has  $\omega = 270^\circ$

$$\Delta r = a_R(1- e_R) - (a_R+\Delta a) \cdot [1+\Delta e - e_R(1- \Delta a/(a_R + \Delta a))]$$

which again simplifies to  $\Delta r = \Delta a - (a_R + \Delta a) \Delta e$

- That is, the separation between the ellipses is approximately the same independent of the orientation of the secondary orbit and with the same approximations is the “outside the envelope” constraint value

## Conclusions

- Couple of comments on previous analysis:
  - Higher order zonal terms contribute a small amount including no longer making  $a \cdot e_F$  a constant, however as discussed in the paper, the combined contributions of  $J_4$ ,  $J_5$  and  $J_6$  are about an order magnitude less; contribution higher terms will be even smaller -> overall Envelope definition is good to 10's of meters if not better (that is, a small percentage of the 500 m Margin)
  - The fact that (for  $J_2$  and  $J_3$ )  $a \cdot e_F$  is a function of the  $\sin(i)$  suggests the Envelope is more applicable to Constellation entry and exit and other sun-synch neighbors rather than random orbital debris, but this could be studied further
- Overall the Envelope definition passed the test and should continue to be utilized

\* “The Eccentric Behavior of Nearly Frozen Orbits,” T.H Sweetser and M.A. Vincent, Proc. Of the AAS/AIAA Astrodynamics Specialist Conference, Hilton Head, South Carolina, August 11-15, 2013